A Comparison of XBT and Triaxus Data with Implications for Sound Speed and Salinity Effects

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OC3570 – Operational Oceanography
Winter 2005 Cruise Report

4 April 2005

1. *Introduction and Background*

With the revival of oceanographic and acoustic concerns in the United States Navy, it is important for today's fleet to investigate equipment options before developing concepts of operations (CONOPS) for engagements with tomorrow's enemy. The fleet has access to a wide variety of tools and sensors, which should be carefully analyzed for function and utility. Two such tools are the expendable bathythermograph (XBT) and the towed vehicle. These two platforms provide options for obtaining temperature and sound speed data, and much more in the case of the towed vehicle. While the XBT is currently the Navy's primary means of obtaining temperature versus depth information for acoustic applications, various other sensor platforms are available. The Triaxus 3D Towed Undulator is one of those platforms, and it is evaluated against the XBT for acoustic purposes in this study.

The Naval Postgraduate School (NPS) winter 2005 Operational Oceanography (OC3570) class performed an oceanographic research cruise onboard the R/V Point Sur from February 1 to February 8, 2005. Each of the two cruise legs left from Moss Landing in the Monterey Bay and extended northward towards Half Moon Bay, along the California Central Coast. Leg 1 took place on February 1 through February 4. Leg 2 took place from February 5 through February 8. Data was collected along several predominantly-cross-shore tracks, which can be seen in the attached figures (see Appendix A, pages 1 and 2). Three cruise tracks were chosen for further analysis in this study.

The purpose of this study is to compare data collected from XBT's with data collected from the Triaxus 3D Towed Undulator. The intent is to collect temperature data from the XBT and temperature plus salinity data from the Triaxus, compute sound speed from each data set, and compare the different parameters from each platform in both quantitative and qualitative schemes. The study quantifies differences in data coverage and evaluates cross sectional plots of different variables. This study is unique in that it covers a large portion of the water column in cross-sectional plots vice in profile-like, one-dimensional snapshots that were seen in previous OC3570 comparison papers. The results are applied to acoustic concerns, and recommendations are made based on sensor characteristics and acoustic implications.

2. *Data and Methods*

The Sippican T7 Expendable Bathythermograph measures temperature to the nearest ± 0.1 °C through a thermistor in the nose. Depth is calculated via calibrated fall rate. The calibration is shown later to be lacking in accuracy, although Sippican claims a depth accuracy of z ± 2 %.[1] Data points are transmitted through the wire back to the ship, recording temperature data at regular intervals of about 0.64 m depth. Another important factor to consider with the XBT is that it assumes a constant value of salinity of 33.5 psu. This introduces a large amount of error into the sound speed calculations, as is shown later.

The Triaxus 3D Towed Undulator provides real time underway data collection. It is designed for high speed data collection, 1-10 kts according to its makers.[2] However, it still limits ship speed for collection in comparison to the Sippican XBT, which is rated at 15 kts for drops.[3] The Triaxus can fit a multitude of different sensor types and platforms onto its carriage. This allows the Triaxus to be much more versatile in different types of data collection efforts in comparison with the XBT and many other less capable oceanographic sensor platforms. Pressure data from the Triaxus is recorded in decimeters. Temperature data and salinity data are recorded for use in calculating sound speed. Several other parameters are collected with the Triaxus, but only the temperature and salinity values are used for further calculations. A nice feature of the Triaxus is that it records its own latitude and longitude in real time as it glides through the water.

The RV Point Sur was used to conduct all of the data collection for this study.

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[1] http://www.sippican.com/stuff/contentmgr/files/0dad831400ede7b5f71cf7885fdeb110/sheet/xbtxsv.pdf
[2] http://www.triaxus.com/filer/1021/TRIAXUS%203D%20Towed%20Undulator.875324074153398.pdf
[3] http://www.sippican.com/stuff/contentmgr/files/0dad831400ede7b5f71cf7885fdeb110/sheet/xbtxsv.pdf

Two sensor platforms were used to collect data, which were the Sippican T7 Expendable Bathythermograph and the Triaxus 3D Towed Undulator. XBT's were dropped along Lines 2 and 3 for Leg 1 and along Line 4b for Leg 2, while the Traixus 3D Towed Undulator was continuously towed along each of these cruise tracks. Ten XBT's were dropped along Line 3 of Leg 1, while eleven XBT's were dropped along Line 2 of Leg 1. However, one of the XBT's was excluded from the Line 2 data in this study, in order to reduce the number to ten and to create a data set that would be directly comparable with that of Line 3. Eight XBT's were dropped along Line 4b of Leg 2. XBT's were dropped approximately every half hour to maximize the density of drops across these cruise track lines for this study. It is important to note that the Navy does not even drop XBT's at this frequency, so data collected in the fleet is even sparser than the XBT data collected for this study. A complete record of the observations from both the XBT's and the Triaxus is in Appendix B. This record includes times and locations of all XBT drops and Triaxus events that are relevant to this study. It also shows the maximum depths to which each sensor platform was deployed for each XBT drop and each Triaxus tow event.

The supporting staff from the NPS Oceanography Department processed all data from the sensors and converted the data into the appropriate format for further analysis. The raw data was concatenated into data type files for each cruise track line so it could be easily manipulated for additional study. A file was created for each data type (e.g. – XBT or Triaxus) matching each of the three chosen cruise track lines. For the Triaxus data, both sound velocity and depth were calculated at each pressure level. The pressure to depth conversion was made using the following relationship:

$$\text{depth(meters)}=[(((-1.82\times10^{-15}*p+2.279\times10^{-10})*p-2.2512\times10^{-5})*p+9.72659)*p]/g$$

where p is pressure in decibars and g is gravity in m/s^2. This relationship assumes an ocean water column where both temperature and salinity are constant at 0 °C and 35 psu respectively.[4] For the XBT data, latitude and longitude needed to be added into the data files for plotting purposes. For both the XBT and the Triaxus data, offshore distance was calculated. This allowed the cross-shore cross sections to be plotted easily in a separate software program. All of the above calculations were carried out in Matlab 7.0, using the Seawater Library routines.[5] Offshore distance was the only exception, which was calculated with a Matlab function, gdist.m, that was a modification of a Seawater Library routine from Fred Bahr, Naval Postgraduate School.

Each of the XBT drops was automatically separated into 1183 vertical levels, between zero and 760.4 m depth. Each Triaxus undulation was separated into approximately 120 vertical levels, but the Triaxus data only reached a maximum of about 150 m depth. There is a significant difference in the vertical resolution of these two profilers. However, the major difference between the two sensor platforms is that the Triaxus records data in the horizontal direction in addition to the vertical. The XBT is very limited in that it can only measure data in a vertical line, essentially giving only a one-dimensional picture of a point location in the ocean. The Triaxus is capable of three-dimensional data collection, but the data sets recorded on this cruise were two-dimensional for data comparison.

As mentioned earlier, the data sets for Line 2 and Line 3 along Leg 1 of the cruise each had 10 XBT drops included. These each carried a total of 12260 data points for the entire data sets. The continuous Triaxus tow for Line 2 had 13336 data points, while the data set for Line 3 had 13046. Line 4b from Leg 2 had 9808 data points from the XBT drops and 13174 data points from the Triaxus. These are the total numbers of data points before the data sets were cut down to comparable scales.

[4] http://www.seabird.com/application_notes/AN69.htm
[5] Morgan, Phillip. Seawater Library. CSIRO

The data sets from the Triaxus were much longer in the horizontal than the concatenated XBT data sets. Thus, they required trimming or resizing for plotting purposes to match the horizontal distance between the first and last XBT drops along the cruise track line. These were matched by using the calculated offshore distance. Likewise, the XBT data sets went much deeper in the vertical than the Triaxus, and they required trimming to 145 m depth. The final six data sets had abscissa data spanning the horizontal distance between the first and last XBT drops along the cruise track line (i.e. – approximately 45 km for each cruise track line) and ordinate data spanning the vertical distance between the ocean surface (z = 0 m) and the bottom of the Triaxus tow, or roughly 150 m. These are the data limits and scales used for the cross sectional data comparisons. At this point in the data processing, the data sets are as close to matching as they can get in parameters, scales, and units. The finalized data sets that are used for comparison can be found in Appendix C, overlaid on top of the gridded and contoured temperature data. These data coverage diagrams can be used for comparison of the cross section plots to show what features are being missed by the XBT data sets and why they are missed based on drop locations.

Three assumptions were made for this study. The first assumption was that the constant salinity value of 33.5 psu for the XBT data. This is built into the software that is used to read the data from the XBT. This is a manufacturer's limitation on the sensor, which introduces error into the sound speed because the XBT does not measure salinity directly. Since sound speed is a function of temperature, salinity, and pressure, this already introduces significant error into the XBT data.[6]

The second assumption was constant ship heading for each cruise track line. This lends to a perfectly straight line of data along the intended ship heading, which is really not the case. However, the ship only varies slightly from its course, so this is a valid assumption.

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[6] Urick, pp. 112-113.

The third, and most important assumption in this study, is that the Triaxus data is accepted as the truth. This is supported by the fact that the Triaxus sensor package undergoes rigorous laboratory calibration, similar to the sensors on a Sea Bird conductivity temperature and depth (CTD) profiler. This assumption is partially valid due to the calibration, but not entirely valid due to the fact that the Triaxus does not cover the entire water column. It does a much better job of painting both vertical and horizontal pictures of the ocean. However, it too has some skip zones between its upsweeps and down sweeps. For purposes of this study, this assumption will be made on account of resolution and data coverage. The small errors associated with the sensors mounted on the Triaxus are beyond the scope of this study.

Data quality control was built into the plotting process. Quality control is carried out by using the filter feature within Surfer that utilizes an averaging technique to determine whether data points are within realistic ranges. This averages data values before and after a given value, and throws out the data point if it falls too far from the averaged value of its neighbors.

The gridding process allows contour plots of the different variables to be generated with ease. However, this is also another source of error. Data points are mapped to a grid, which is then used to assign interpolated values. The interpolation between data points is much less reliable in the XBT case, due to the distance between XBT drops.

The Surfer software program also incorporates built-in math tools, which can be used to perform math functions on the gridded data fields. One of these tools is a differencing capability that allows the subtraction of one gridded data field from another. Several differencing plots are included in the appendices. In this study, the XBT values are always subtracted from the Triaxus values to produce differences that depict anomalies from the Triaxus "truth" values.

Plotting in Surfer is a much less complex task than plotting in Matlab 7.0. Once all of the fields are gridded, simple plot commands allow for contoured cross sections to be produced with ease. This is beneficial when generating a large number of plots. The most difficult aspect of the plotting process was matching the contour intervals and plot legends. All contour intervals and plot legends for comparative charts are on the same scales, and the colors are uniform throughout each data type. The difference plots obviously have different magnitudes imbedded in the legends than the normal plots, but the color schemes show the same trends in positive and negative values.

Instead of using longitude as the abscissa, offshore distance is used in order to make cross sections that are scaled correctly. Note that all attached cross section plots show data along the actual cruise tracks, which was collected in situ by the XBT's and the Triaxus towed vehicle. The plots make use of the assumption that the ship was headed straight along a constant course and bearing.

3. *Results*

The results of this study are derived mostly from the plots produced in Surfer. Temperature, salinity, and sound speed plots were made for all three XBT data sets and for all three Triaxus data sets. These plots show oceanographic features such as internal waves, eddies. Clear differences in data coverage, resolution, and data magnitude can be seen in these plots. Visual inspection was the primary method used to detect features in these plots for comparison of the charts.

The data contained within the original set of plots was then subtracted to produce difference plots, which show the mathematical difference between the Triaxus and the XBT data sets. Difference charts were made for each variable, including temperature, salinity, and sound speed. The differencing was the primary quantitative technique used in this study. After the differencing operations were complete, data analysis was done through visual inspection, as in the original plots.

In Appendix D, the original Triaxus plots are on the top of the page, the XBT plots are in the middle of the page, and the difference plots are at the bottom. These plots can be viewed systematically as "truth" (i.e. – Triaxus data), experimental data with error (i.e. – XBT data), and the difference between the two, or "anomaly". This anomaly could be called "error", but there is some inherent error in the Triaxus data, as well.

The temperature plots in Appendix C are overlaid with the data in order to show data discrepancies and voids in coverage. Obvious data sparse regions can be seen in the XBT plots, while the Triaxus plots have more evenly spread data. Because of the more even data field, it can be inferred that the Triaxus data gives a much more accurate representation of the ocean conditions than does the XBT data.

4. ***Discussion***

On page 1 of Appendix D, the first clear difference between the Triaxus and XBT plots is the difference in the depiction of high frequency variability. The Triaxus plot shows a much higher resolution representation of oceanographic features. The most significant differences between the XBT and Triaxus data occur in the spaces between the XBT data lines, where the Triaxus collects data during its horizontal excursions. The difference chart at the bottom of page 1 of Appendix D shows a clear positive anomaly in the thermocline at the 60 km offshore point. In addition, several smaller discrepancies occur along the thermocline between 25 and 30 km offshore.

On page 2 of Appendix D, a warm core eddy is seen by both the Triaxus and the XBT's. From this easy detection of the feature in this XBT plot, it may be concluded that it is actually easier to see larger, mesoscale features in the smoothed XBT data than it is in the high resolution Triaxus. The high frequency undulations seen in the Triaxus data can actually mask some of the larger scale circulation features. However, the finer scale features, such as internal waves, should show up well in the Triaxus data. In addition, the data anomalies shown on the difference chart on page 2 of Appendix D confirm columns of bad agreement between the XBT drops. These columns are where the XBT data set smoothed over several microscale features, and internal wave crests and troughs caused large discrepancies between the data sets.

Most notably on page 3 of Appendix D, there is a surface artifact shown in the XBT data that is not present in the Triaxus data. The closely spaced isotherms at the top of the picture are artifacts that can be attributed to the storage temperature of the XBT. The packed contours near the sea surface on the XBT plots simply result from the XBT quickly changing temperature and adjusting from the storage temperature to the sea surface temperature. This can be avoided by storing the XBT's on the deck, where sea surface temperature and air temperature are in closer agreement.

Appendix E covers the salinity collected from the Triaxus and compares it to the assumed constant salinity value of 33.5 psu from the XBT's. The first plot on each page of Appendix E is the actual salinity data recorded from the Triaxus. The second plot on each page shows the XBT assumed value of 35 psu subtracted from the collected Triaxus salinity values.

There is obvious variability that is missed by the XBT salinity assumption. Salinity values change up to 1 psu between the surface and 145 m depth on these plots. There are also two important salinity features to note. On page 2 of Appendix E, there is an obvious vertically sloping feature in the halocline at 50 km offshore. This steep slope may be a salinity front or just a small local disturbance that could affect sound rays significantly. In addition, there is a feature at the bottom right hand corner of the plots on page 3 of Appendix E that could either be bad data or a similar salinity front feature.

The sound speed results shown in Appendix F show the most significant shortcomings of the XBT. The most important discrepancy to note from this entire study is that the XBT sound speeds are always biased to the slow side near the surface (i.e. – throughout this entire 0-145 m test depth), due to a warm temperature bias. When XBT sound speed is subtracted from Triaxus sound speed, the values across almost the entire plots are positive anomalies. All three difference charts in Appendix F show primarily positive differences, which correspond to negative anomalies between Triaxus and XBT data. Since sound speed decreases with depth in these plots, this negative XBT sound speed anomaly suggests that the probe is actually deeper than the recorded depth. This also then suggests that the fall rate calibration performed by Sippican that is used to calculate the depth of the probe is not very accurate, erring on the slow side. Positive differences across most of the charts would imply that there is a serious issue with the way the depth calculations are being carried out. This also suggests that the XBT's record the thermocline at a shallower depth than actual.

This is another important result gathered from the plots. Most of the variability and differences between the XBT and Triaxus data occurs in the thermocline. Obviously, this is where a lot of the high frequency variability occurs within the ocean, but this might also suggest that there is a regular difference between the location at which the Triaxus places the thermocline and that at which the XBT's place the termocline. Differences in thermocline depths have significant acoustic implications.

On page 2 of Appendix F, there is an important feature to note. The negative anomaly at 53 km offshore is most likely due to the salinity front that can be seen on the salinity chart on page 2 of Appendix E. Appendix F shows that this created a 4 m/s difference in sound speed, which could be acoustically significant in sound ray refraction.

5. *Conclusion*

Previous studies showed low error in the XBT versus CTD data and low impacts to operations.[7] In this study, the plots speak for themselves, showing a lot of high frequency variability that cannot be exploited through the use of XBT's.

[7] Fang, pp. 14.

It may be beneficial to use XBT's over Triaxus for climatological databases and for ocean characterization studies. The warm eddy seen on page 2 of Appendix D is actually easier to see in the XBT data than it is in the Triaxus. The high frequency variability is averaged out of the data in climatological databases anyways, and apparently in the XBT data, as well.

The XBT's show a clear warm bias due to depth errors, and they show clear neglect of salinity variability up to nearly 1 psu across the scaled water column. The warm bias shown by the XBT's causes increased upward refraction in the sound ray paths, which may cause fleet operators to not exploit the environment properly.

The depth error seen in thermocline variability could cause an error in mixed layer depth with implications for ducting. A few decameters difference in mixed layer depth could mean a difference of a few kiloyards in detection range or propagation loss in a surface duct. It also affects low frequency cutoff, which is used to determine operating frequencies within certain layers of the water column.

Triaxus-type sensors would improve environmental sampling in the operating envelope but not deeper. This is because the Triaxus has an operational depth limit of about 150 m. The submarine operating envelope goes deeper than this, so an improved operating depth limit on the Triaxus would be a big improvement.

The missed salinity features may be important, as well. The biggest salinity feature discussed caused a 4 m/s difference in sound speed. This could cause significant differences in arrival times of acoustic echoes, and more importantly it could cause major bending of sound rays towards or away from friendly sensors.

The high frequency variabilities that are seen in the Triaxus data but not in the XBT data sets would affect higher frequency acoustic signals much more than they would affect lower frequencies.

For areas where higher acoustic frequency ranges are called for, Triaxus-type sensors would be the sensors of choice for preparing the battlespace.

Acknowledgements

Special thanks to Mr. Tarry Rago, Naval Postgraduate School, for helping with the data processing for this study.

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Fang, Chin-lung. "XBT/CTD Comparisons." Naval Postgraduate School, 2002.

http://www.sippican.com/stuff/contentmgr/files/0dad831400ede7b5f71cf7885fdeb110/sheet/xbtxsv.pdf

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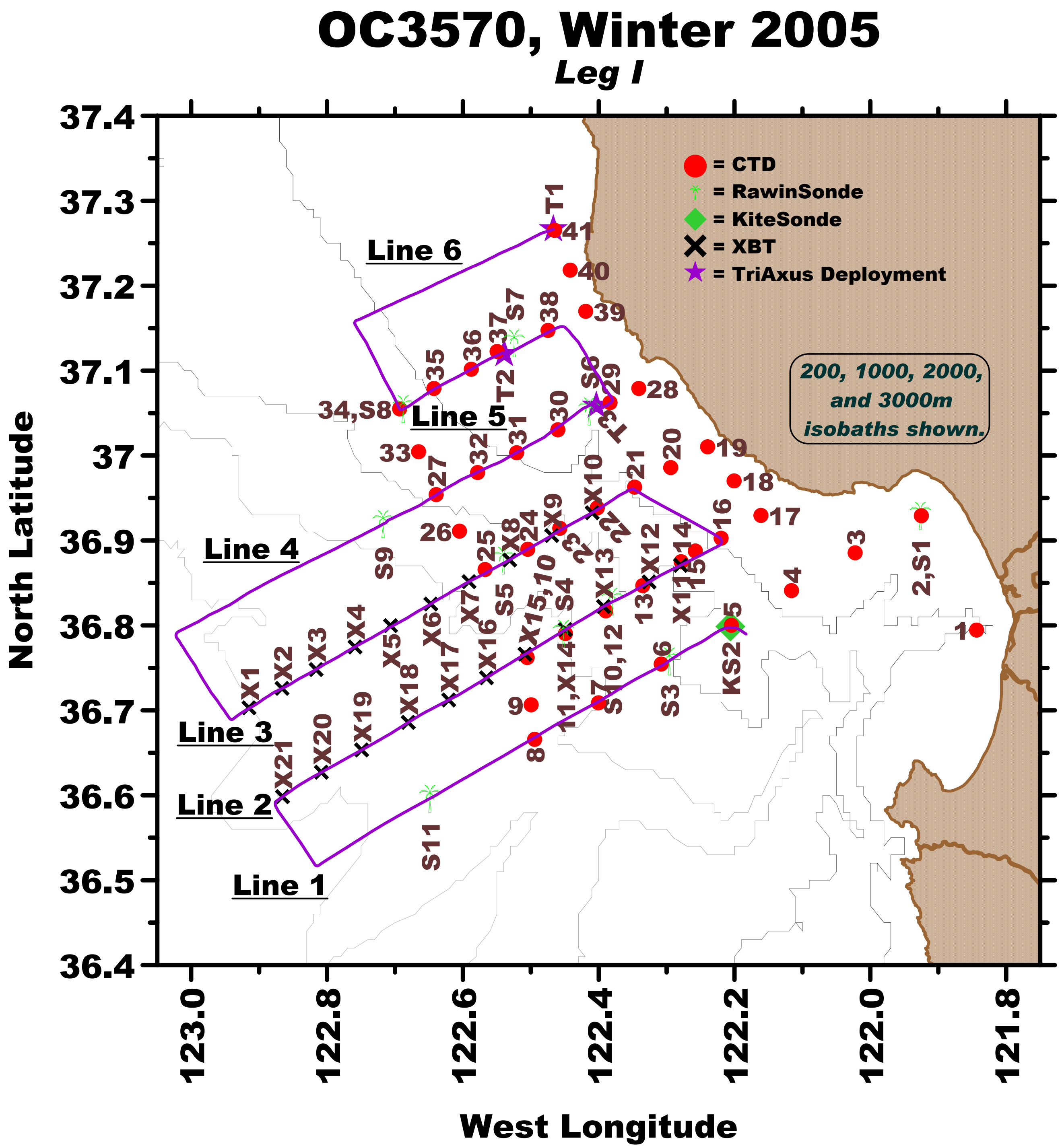
http://www.seabird.com/application_notes/AN69.htm

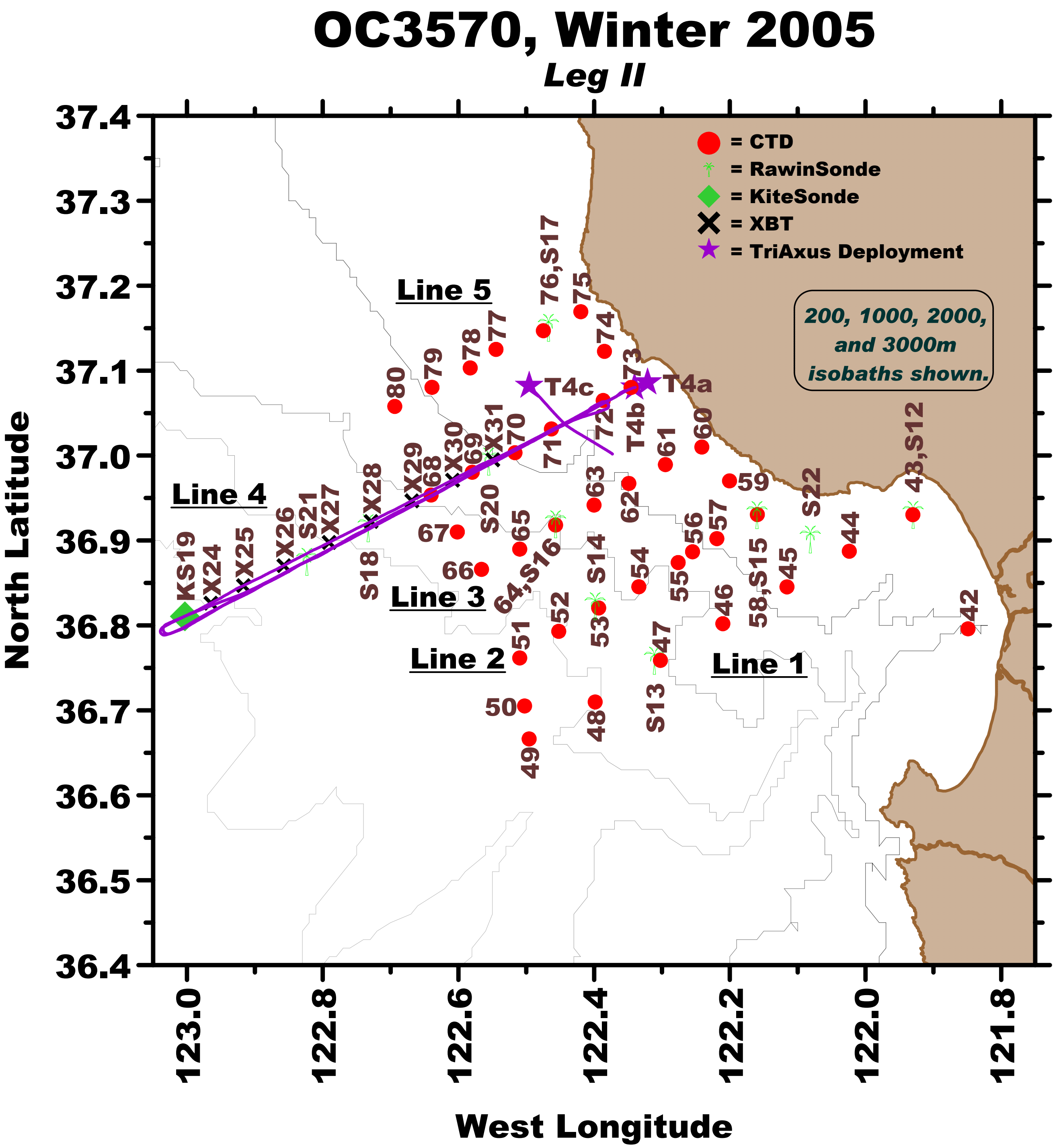
Matlab routines derived from the Seawater Library of Phillip Morgan, CSIRO.

Urick, Robert J. Principles of Underwater Sound. 3rd Ed. Los Altos: PeninsulaPublishing, 1983.

Appendix A



OC3570, Winter 2005
Leg I
North Latitude
West Longitude
= CTD
= RawinSonde
= KiteSonde
= XBT
= TriAxus Deployment
200, 1000, 2000, and 3000m isobaths shown.
Line 1
Line 2
Line 3
Line 4
Line 5
Line 6


OC3570, Winter 2005
Leg II
= CTD
= RawinSonde
= KiteSonde
= XBT
= TriAxus Deployment
200, 1000, 2000, and 3000m isobaths shown.
Line 1
Line 2
Line 3
Line 4
Line 5
T4a
T4b
T4c
North Latitude
West Longitude
37.4
37.3
37.2
37.1
37.0
36.9
36.8
36.7
36.6
36.5
36.4
123.0
122.8
122.6
122.4
122.2
122.0
121.8

Appendix B

CRUISE REPORT—OC3570, 1-8 February, 2005

Station	Position		Depth (dbar)	Time (UTC)	Comments
February 3, 2005					
Triaxus 1	37-15.99	122-28.01	(to) 150.0	1435	Deploy
Sonde 8	37-03.29	122-41.28	----	1800	
Triaxus 1	37-07.22	122-32.27	(to) 150.0	1922	Recover—snagged crab pot.
Triaxus 2	37-07.17	122-32.35	(to) 150.0	1934	Deploy
Triaxus 2	37-03.20	122-24.24	(to) 150.0	2132	Recover—snagged crab pot.
Triaxus 3	37-03.52	122-24.21	(to) 150.0	2140	Deploy
February 4, 2005					
XBT 1	36-42.18	122-54.90	760.0	0349	Bad > 445m?
XBT 2	36-43.55	122-51.97	760.0	0429	
XBT 3	36-44.88	122-48.97	760.0	0457	
XBT 4	36-46.48	122-45.53	760.0	0529	
XBT 5	36-47.98	122-42.39	760.0	0557	
XBT 6	36-49.51	122-38.83	760.0	0629	
XBT 7	36-51.09	122-35.46	760.0	0658	
XBT 8	36-52.62	122-31.87	760.0	0728	
XBT 9	36-54.35	122-28.15	760.0	0800	
XBT 10	36-55.96	122-24.58	760.0	0829	
XBT 11	36-52.25	122-16.77	760.0	1035	
XBT 12	36-51.07	122-19.55	760.0	1058	
XBT 13	36-49.34	122-23.58	760.0	1131	
XBT 14	36-47.71	122-26.96	760.0	1159	
XBT 15	36-45.97	122-30.52	760.0	1229	
XBT 16	36-44.30	122-33.92	760.0	1258	
XBT 17	36-42.73	122-37.25	760.0	1327	
XBT 18	36-41.15	122-40.83	760.0	1356	
XBT 19	36-39.20	122-44.95	760.0	1430	
XBT 20	36-37.63	122-48.50	760.0	1458	
XBT 21	36-35.90	122-51.94	760.0	1524	
Triaxus 3	36-47.38	122-10.95	(to) 150.0	2140	
End Triaxus work.					

Arrive MLML @ 2351Z on 4 February 2005. End Leg I.

Depart MLML @ 1632Z on 5 February 2005. Begin Leg II.

Station	Position		Depth (dbar)	Time (UTC)	Comments
February 4, 2005					
Begin Triaxus work.					
TriAxus 4a	37-05.17	122-19.27	20.0	1729-1741	Only in water: not collecting data yet.
TriAxus 4b	37-04.81	122-20.43	(to) 150.0	1741	Recording data
February 8, 2005					
XBT 24	36-49.57	122-57.89	760.0	0003	No XBT22 or 23
XBT 25	36-50.81	122-55.01	760.0	0028	
XBT 26	36-52.22	122-51.43	760.0	0057	
XBT 27	36-53.86	122-47.43	760.0	0131	

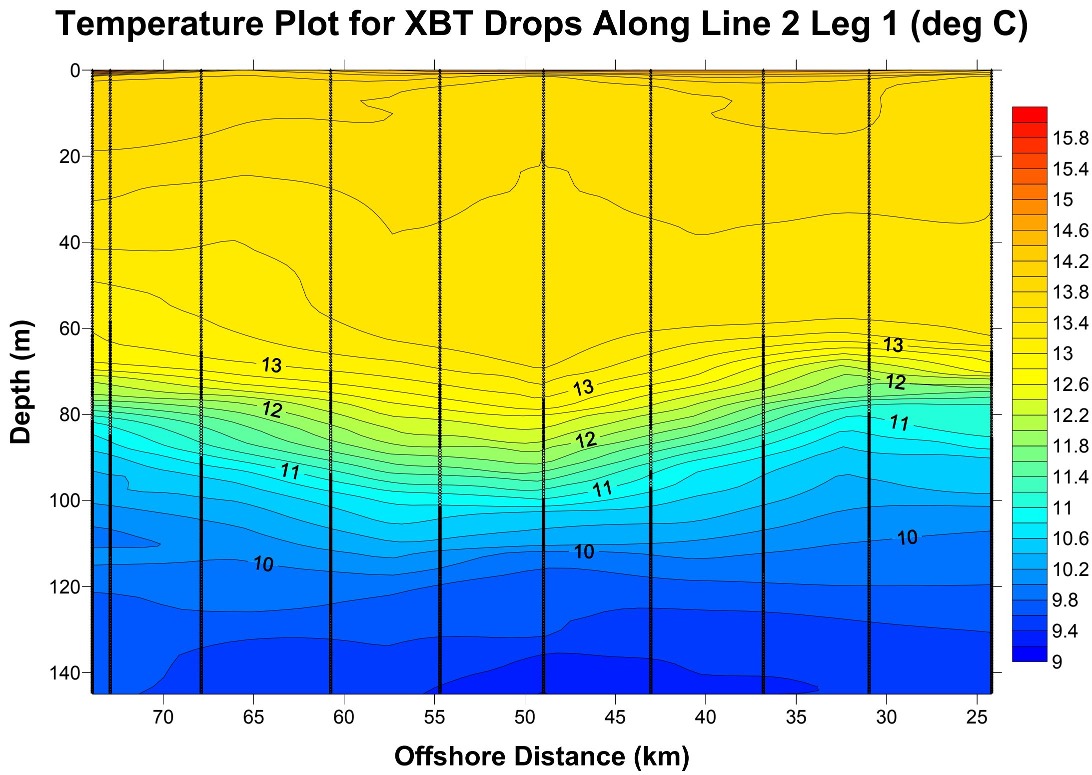
Appendix B

XBT 28	36-55.34	122-43.72		760.0	0201	
XBT 29	36-56.80	122-40.12		760.0	0230	
XBT 30	36-58.26	122-36.52		512.5	0302	Hit bottom.
XBT 31	36-59.70	122-32.96		239.0	0328	Hit bottom.
TriAxus 4b	37-04.54	122-21.24	(to)	150.0	1537	Recover-- snagged crab pot. Severed comms to fish.
TriAxus 4c	37-04.93	122-29.74	(to)	150.0	1815	Deploy
	TriAxus 4c includes run at 25m for onboard ADCP calibration.					
TriAxus 4c	37-00.12	122-22.40	(to)	150.0	1925	Recover-- power shorted to fish.

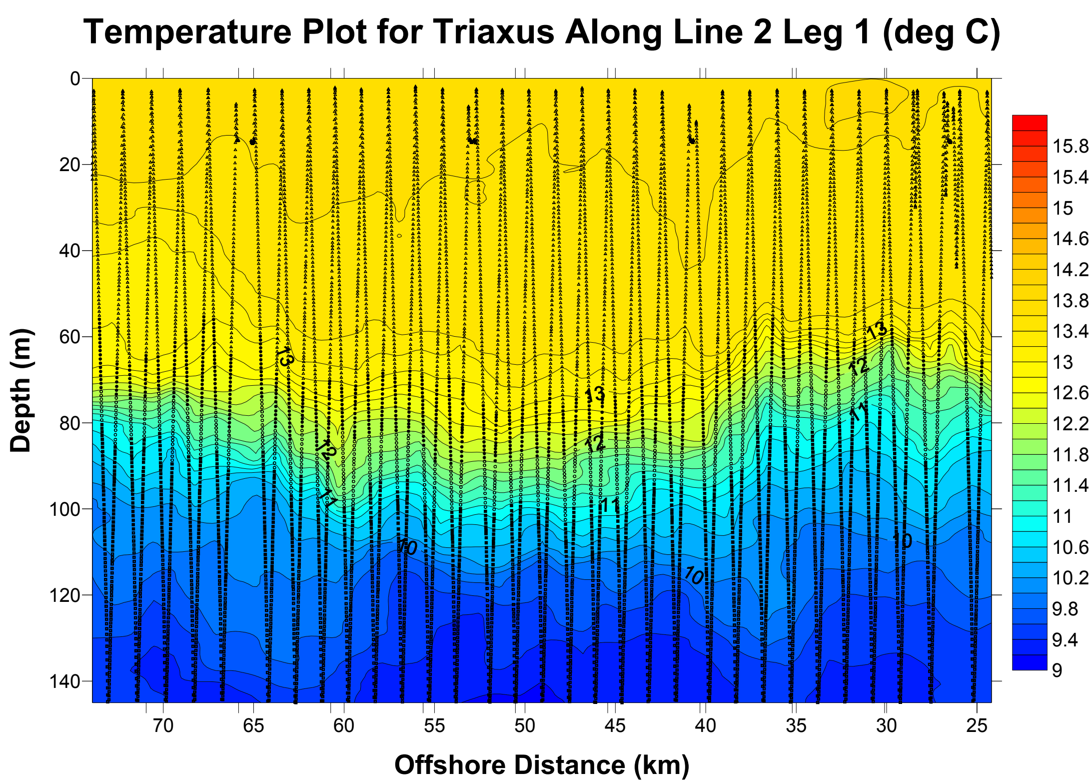
End Triaxus work.

Arrive MLML @ 2308Z on 8 February 2005.

Appendix C

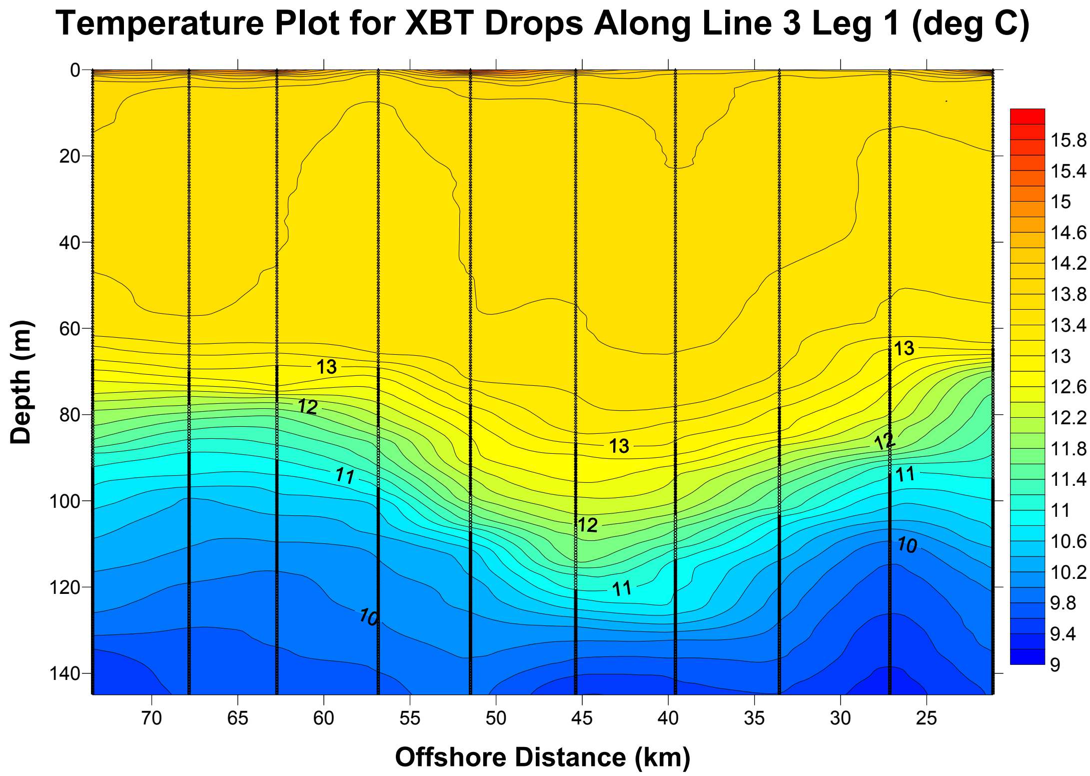


Temperature Plot for XBT Drops Along Line 2 Leg 1 (deg C)
Depth (m)
Offshore Distance (km)



Temperature Plot for Triaxus Along Line 2 Leg 1 (deg C)
Depth (m)
Offshore Distance (km)

Appendix C


Temperature Plot for XBT Drops Along Line 3 Leg 1 (deg C)
Depth (m)
Offshore Distance (km)
0
20
40
60
80
100
120
140
70
65
60
55
50
45
40
35
30
25
13
12
11
10
15.8
15.4
15
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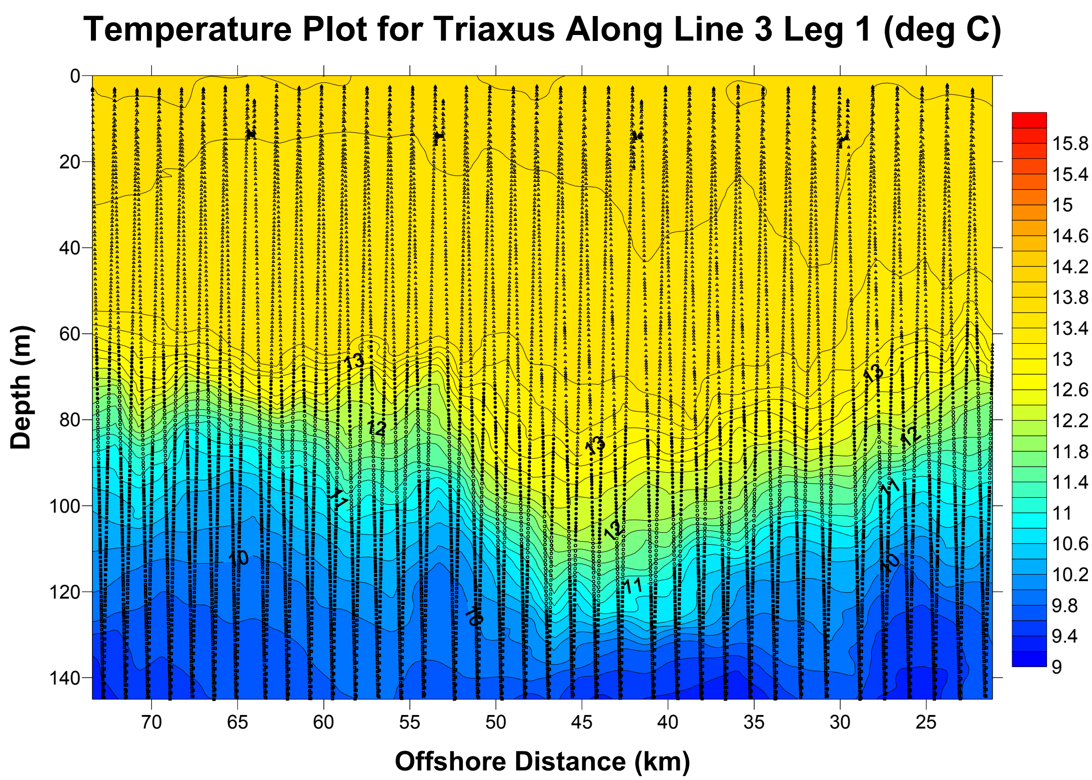
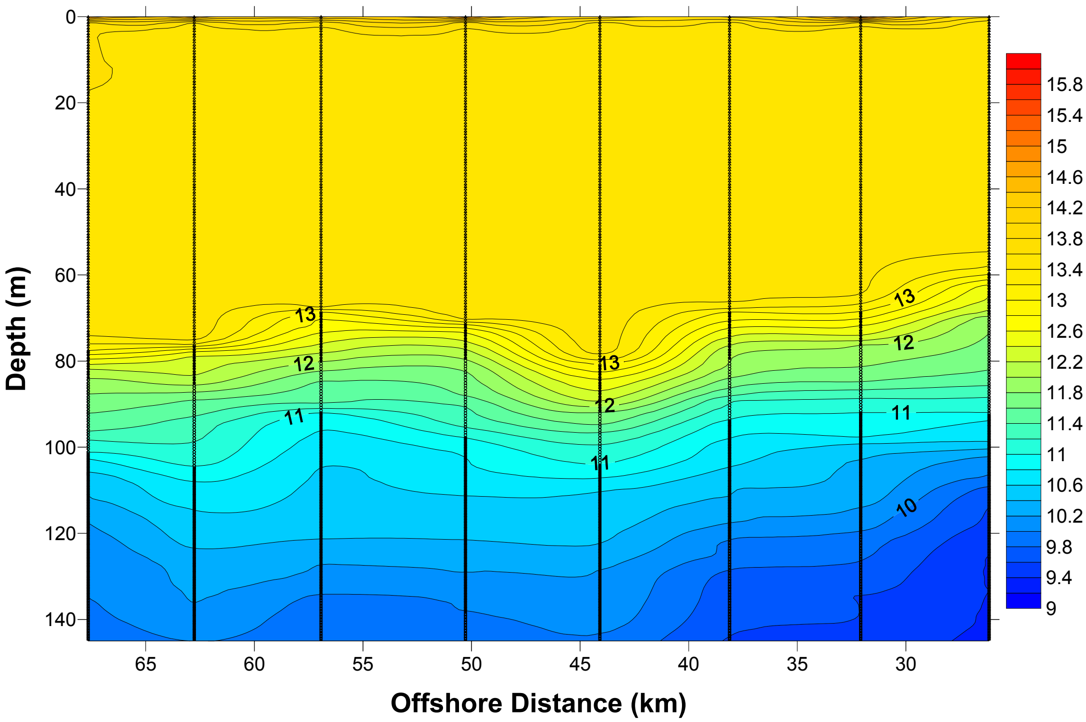
9.8
9.4
9

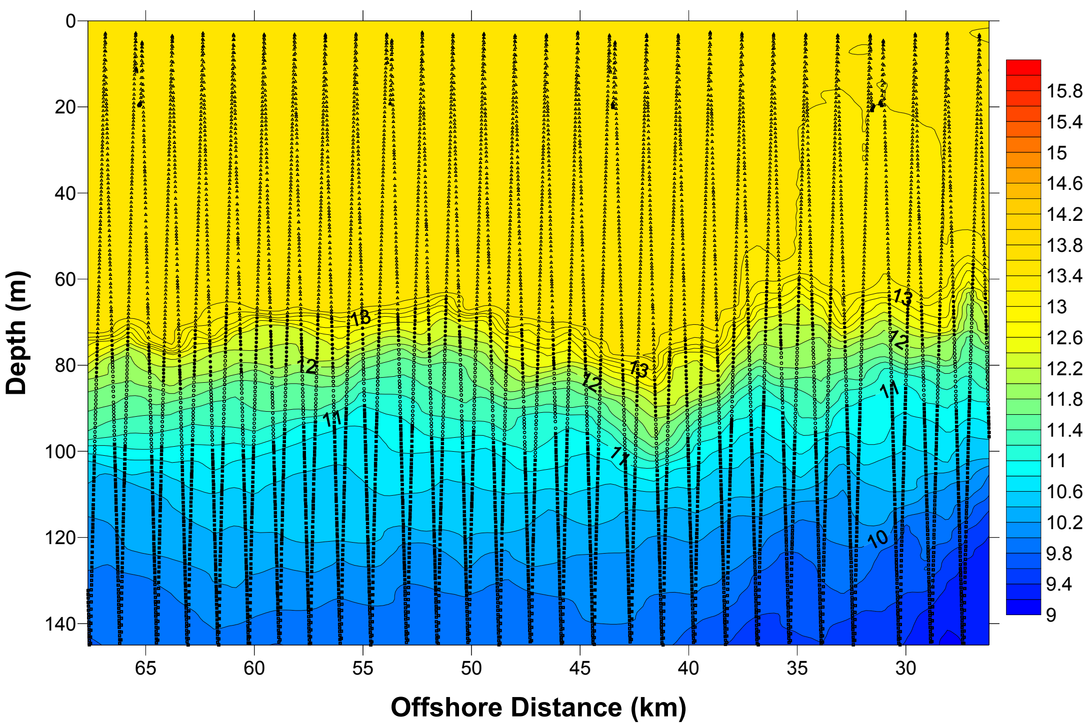

Temperature Plot for Triaxus Along Line 3 Leg 1 (deg C)
Depth (m)
Offshore Distance (km)
0
20
40
60
80
100
120
140
70
65
60
55
50
45
40
35
30
25
13
12
11
10
15.8
15.4
15
14.6
14.2
13.8
13.4
12.6
12.2
11.8
11.4
10.6
10.2
9.8
9.4
9

Appendix C

Temperature Plot for XBT Drops Along Line 4b Leg 2 (deg C)

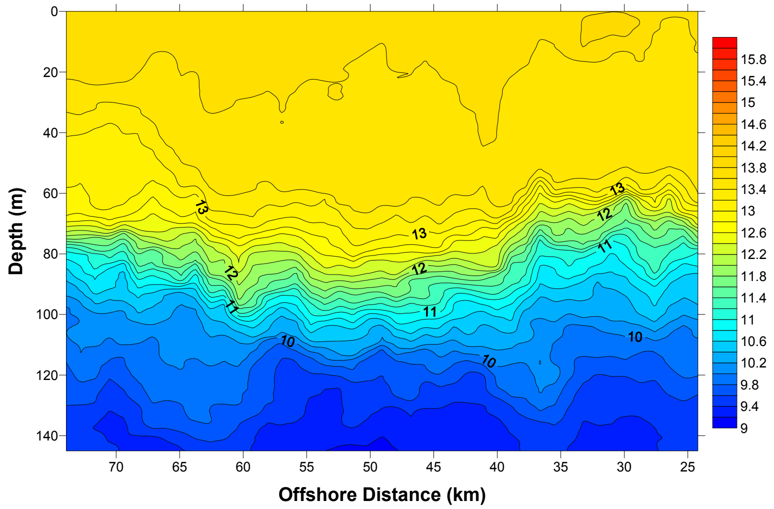


Temperature Plot for Triaxus Along Line 4b Leg 2 (deg C)

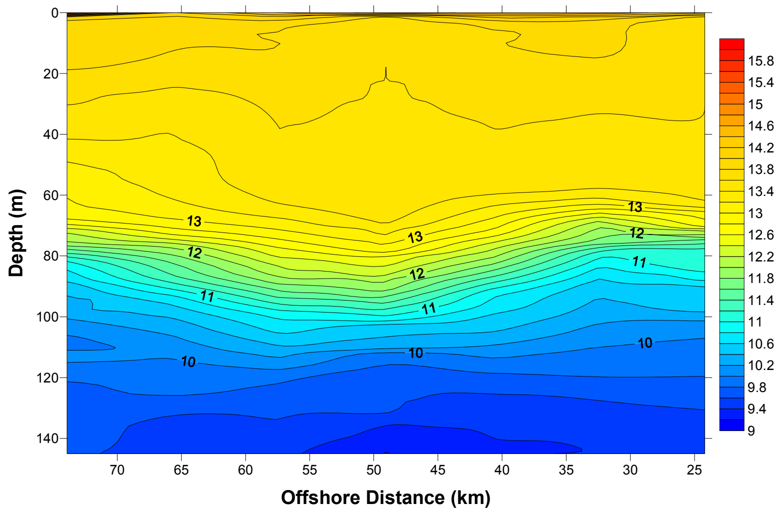


Appendix D

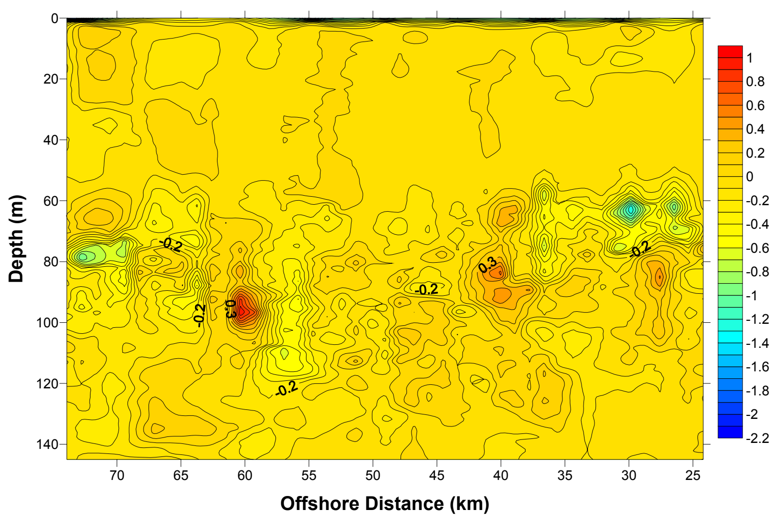
Temperature Plot for Triaxus Along Line 2 Leg 1 (deg C)



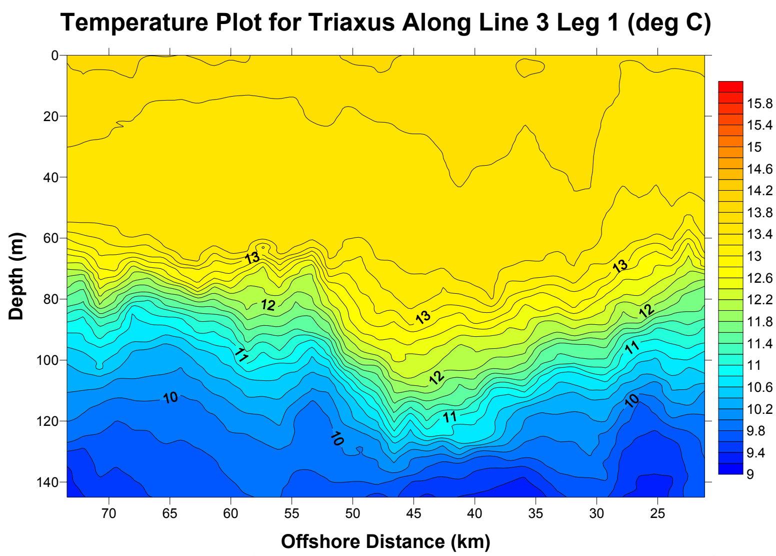
Temperature Plot for XBT Drops Along Line 2 Leg 1 (deg C)



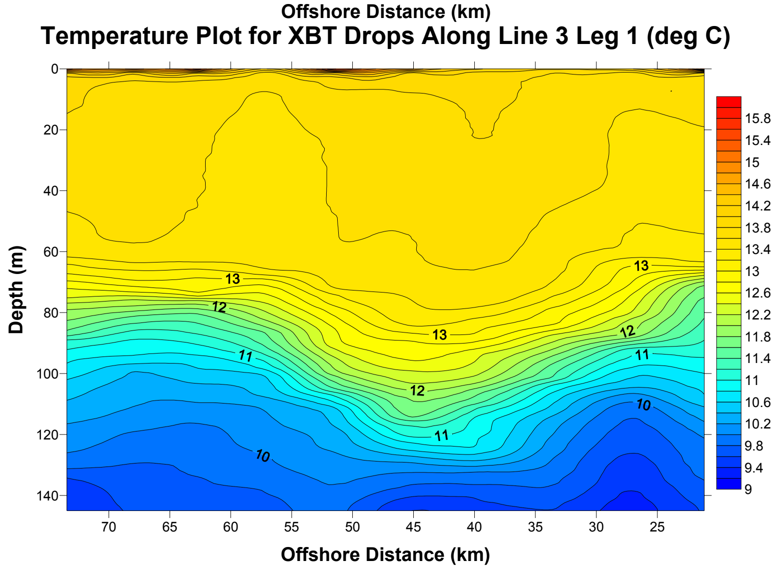
Temperature Difference Plot Along Line 2 Leg 1 (deg C)



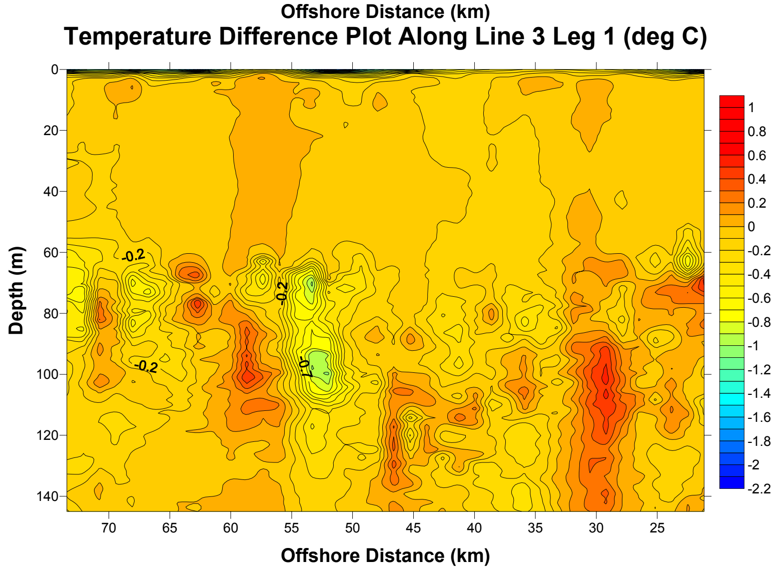
Appendix D



Temperature Plot for Triaxus Along Line 3 Leg 1 (deg C)
Depth (m)
Offshore Distance (km)

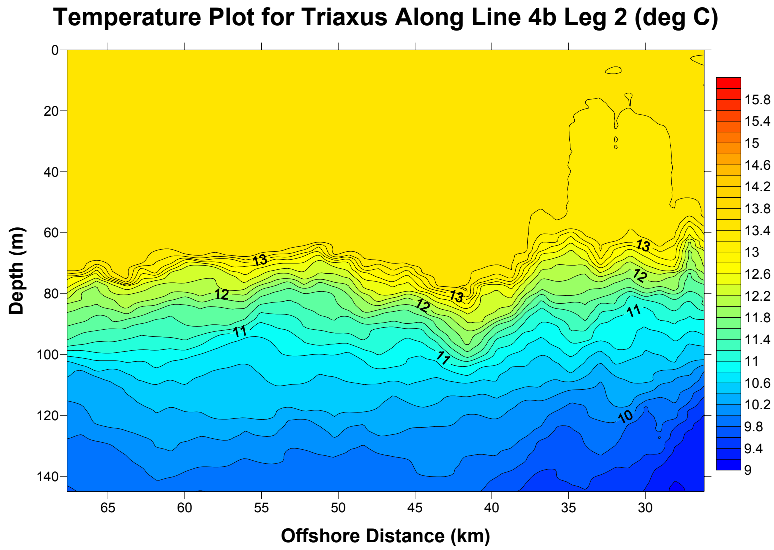


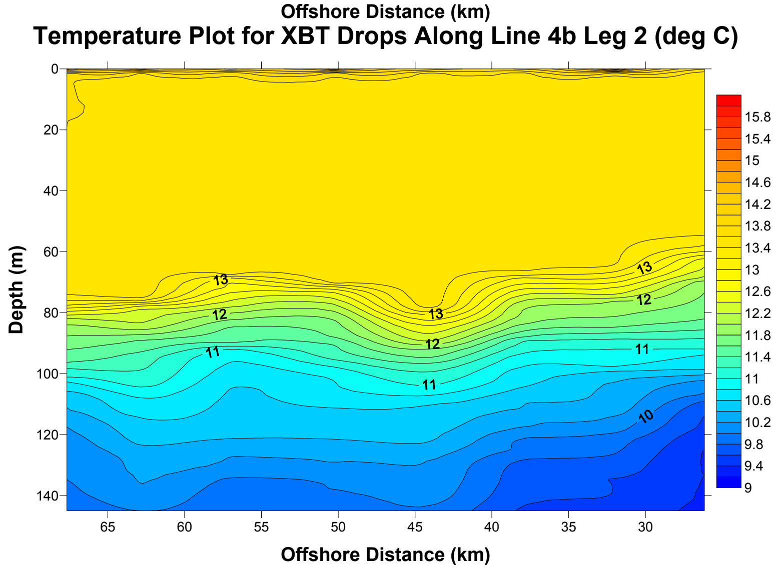
Temperature Plot for XBT Drops Along Line 3 Leg 1 (deg C)
Depth (m)
Offshore Distance (km)

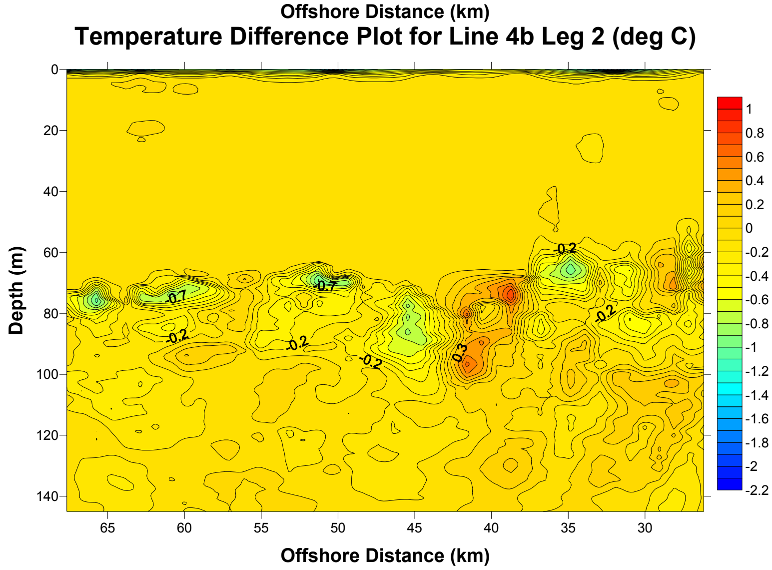


Temperature Difference Plot Along Line 3 Leg 1 (deg C)
Depth (m)
Offshore Distance (km)

Appendix D

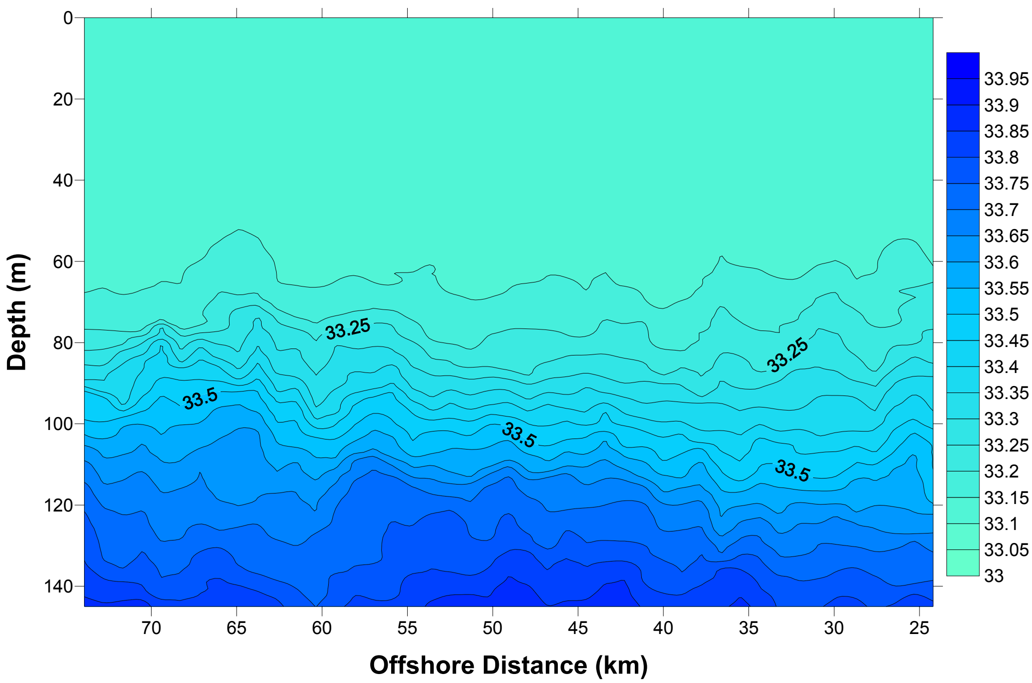

Temperature Plot for Triaxus Along Line 4b Leg 2 (deg C)
Depth (m)
Offshore Distance (km)
15.8
15.4
15
14.6
14.2
13.8
13.4
13
12.6
12.2
11.8
11.4
11
10.6
10.2
9.8
9.4
9


Temperature Plot for XBT Drops Along Line 4b Leg 2 (deg C)
Depth (m)
Offshore Distance (km)
15.8
15.4
15
14.6
14.2
13.8
13.4
13
12.6
12.2
11.8
11.4
11
10.6
10.2
9.8
9.4
9

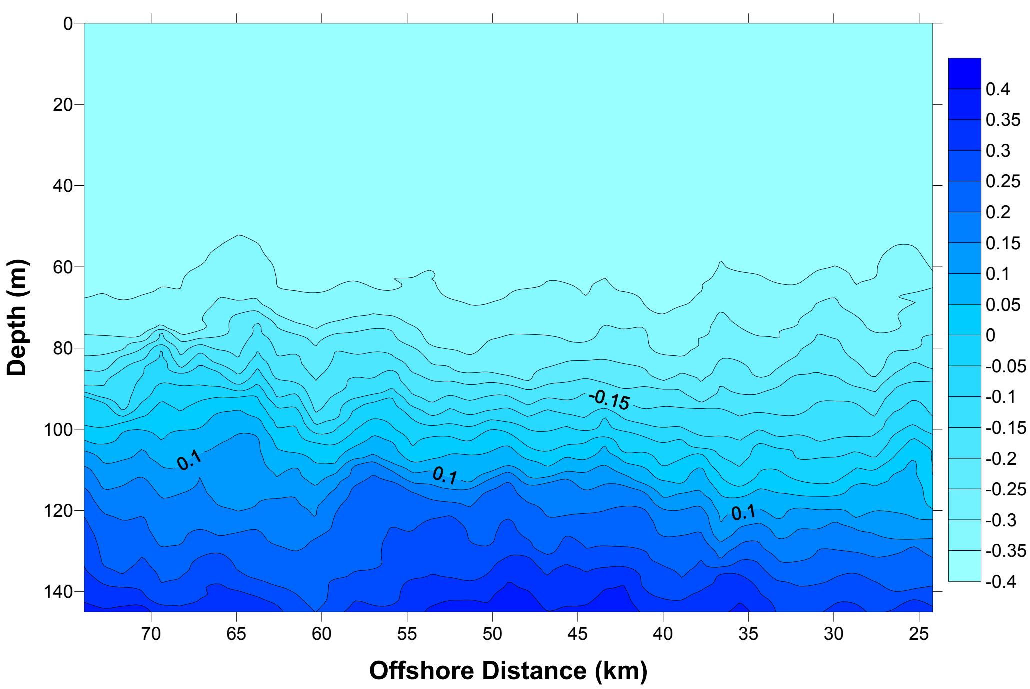

Temperature Difference Plot for Line 4b Leg 2 (deg C)
Depth (m)
Offshore Distance (km)
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4
-1.6
-1.8
-2
-2.2

Appendix E

Salinity Plot for Triaxus Along Line 2 Leg 1 (psu)

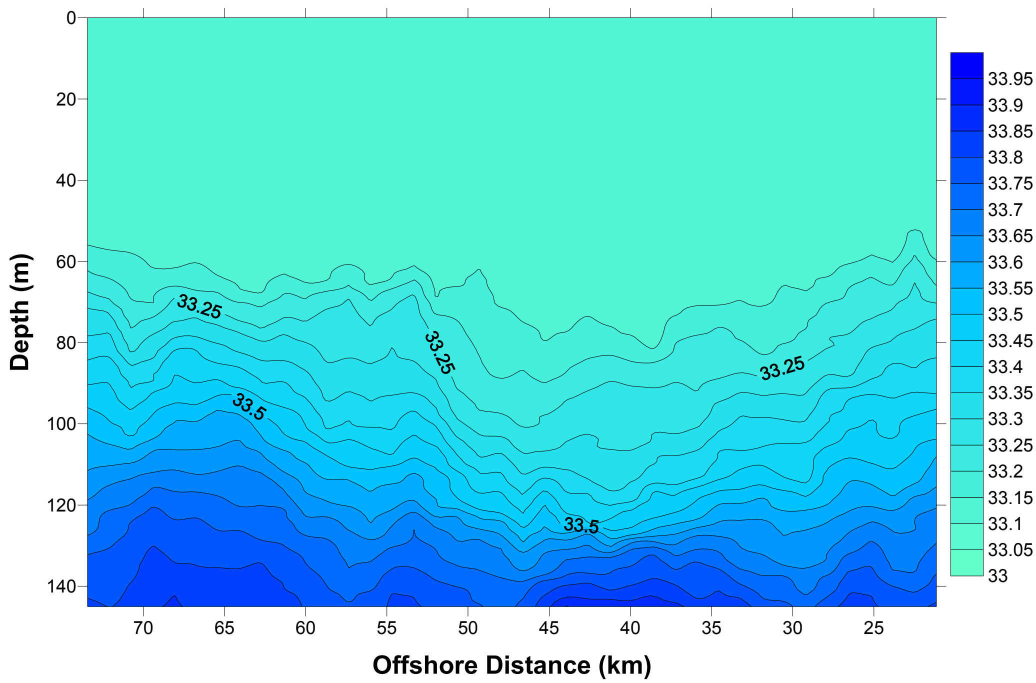


Salinity Difference Plot for Line 2 Leg 1 (psu)

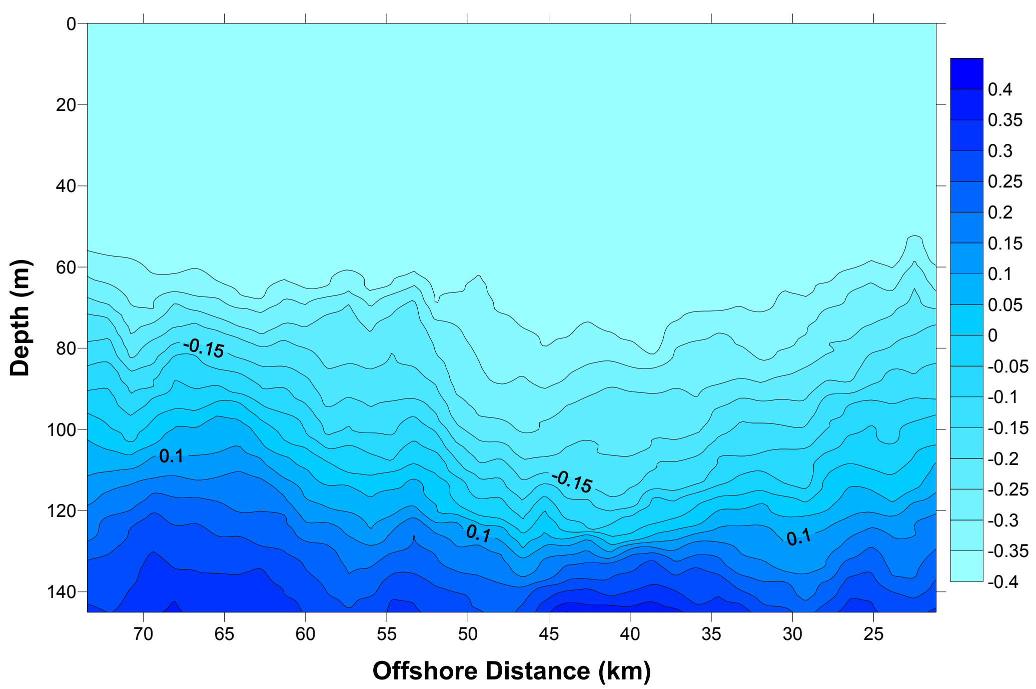


Appendix E

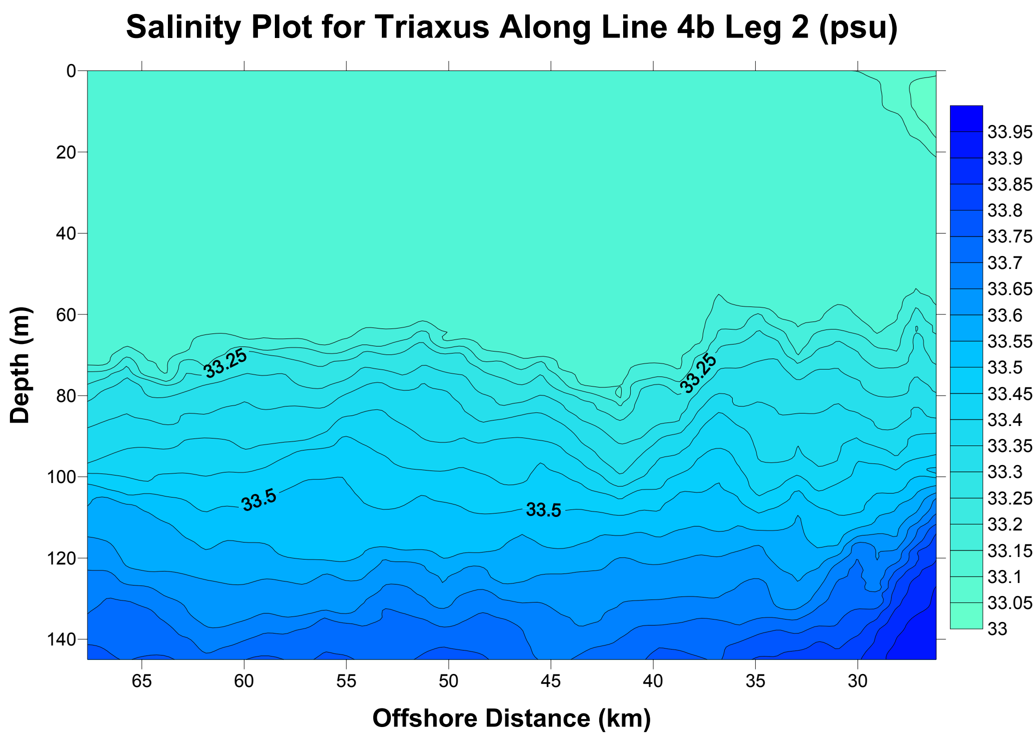
Salinity Plot for Triaxus Along Line 3 Leg 1 (psu)

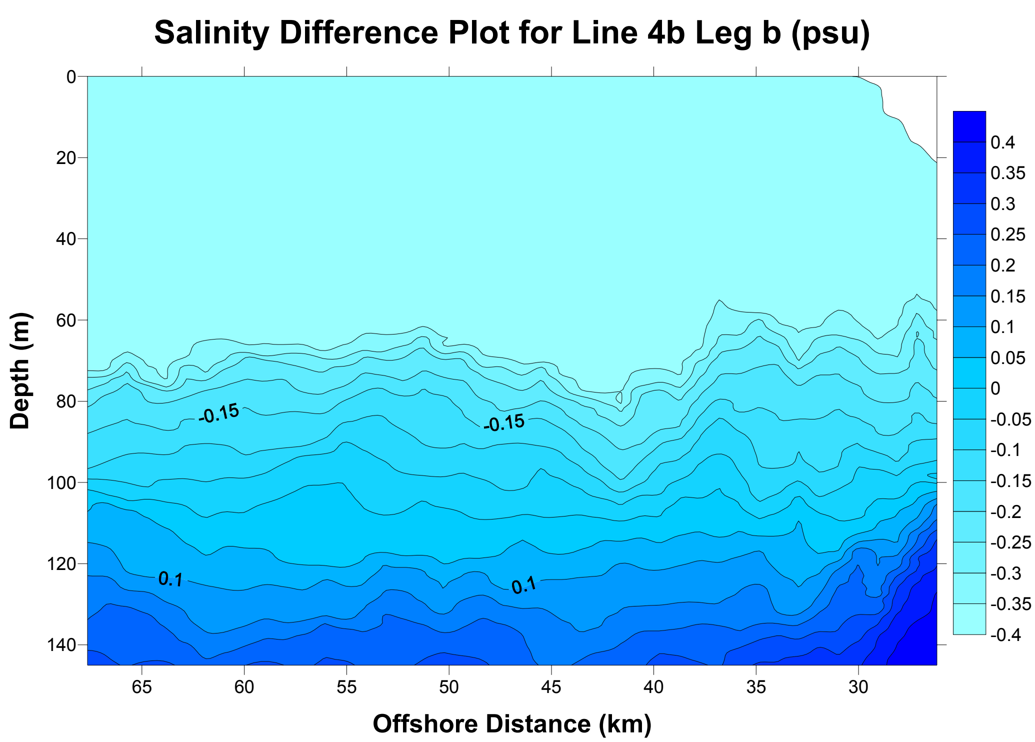


Salinity Difference Plot for Line 3 Leg 1 (psu)



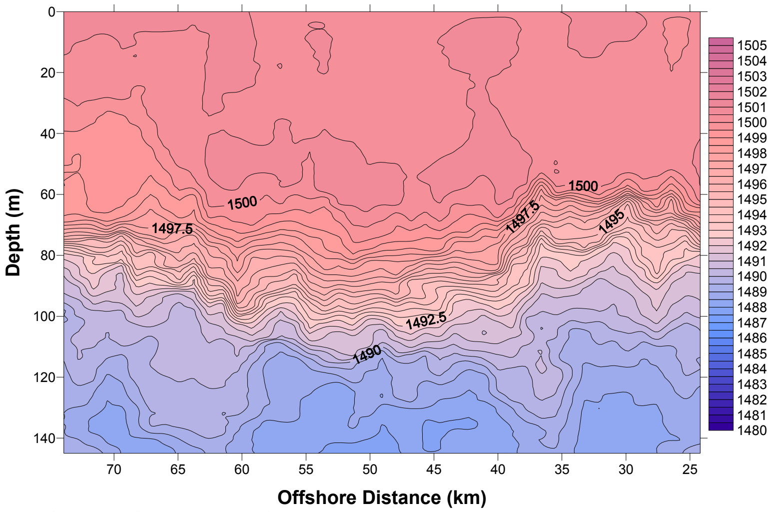
Appendix E


Salinity Plot for Triaxus Along Line 4b Leg 2 (psu)
Depth (m)
0
20
40
60
80
100
120
140
33.25
33.25
33.5
33.5
65
60
55
50
45
40
35
30
Offshore Distance (km)
33.95
33.9
33.85
33.8
33.75
33.7
33.65
33.6
33.55
33.5
33.45
33.4
33.35
33.3
33.25
33.2
33.15
33.1
33.05
33

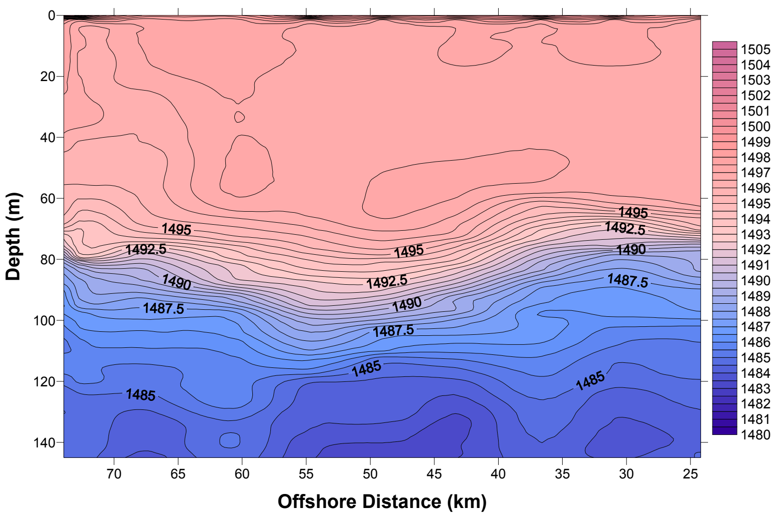

Salinity Difference Plot for Line 4b Leg b (psu)
Depth (m)
0
20
40
60
80
100
120
140
-0.15
-0.15
0.1
0.1
65
60
55
50
45
40
35
30
Offshore Distance (km)
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
-0.25
-0.3
-0.35
-0.4

Appendix F

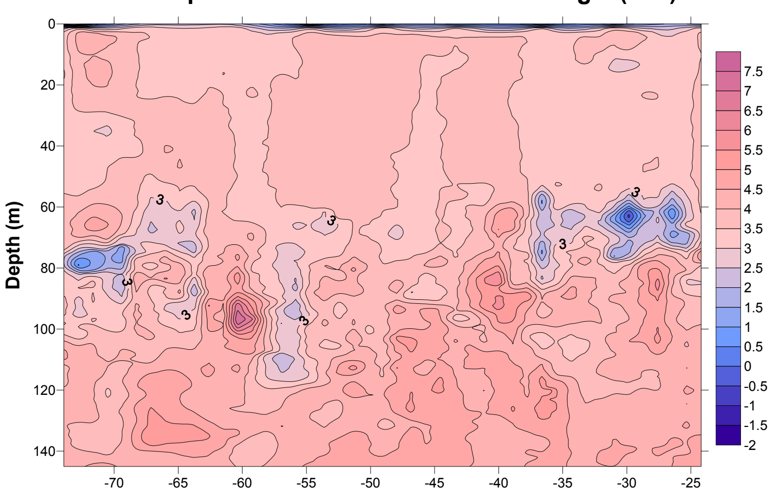
Sound Speed Plot for Triaxus Along Line 2 Leg 1 (m/s)



Sound Speed Plot for XBT Drops Along Line 2 Leg 1 (m/s)

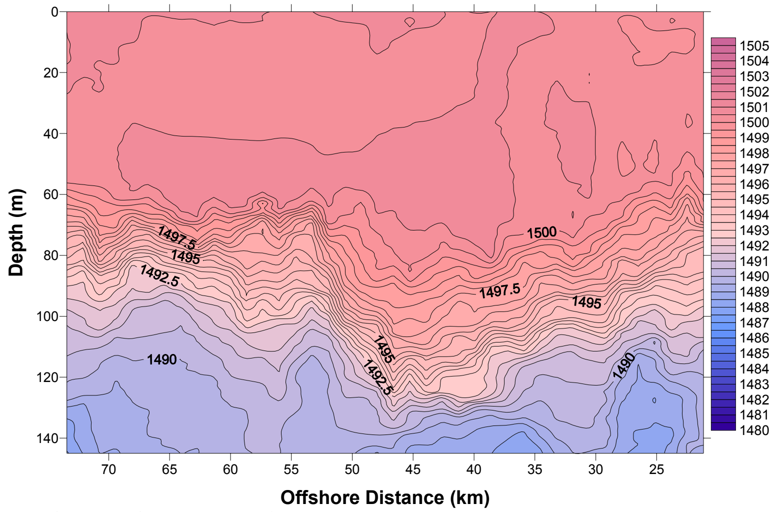


Sound Speed Difference Plot for Line 2 Leg 1 (m/s)

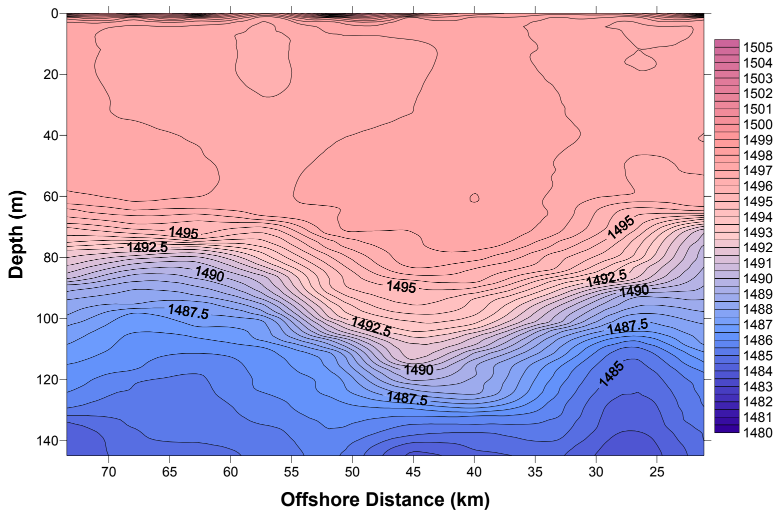


Appendix F

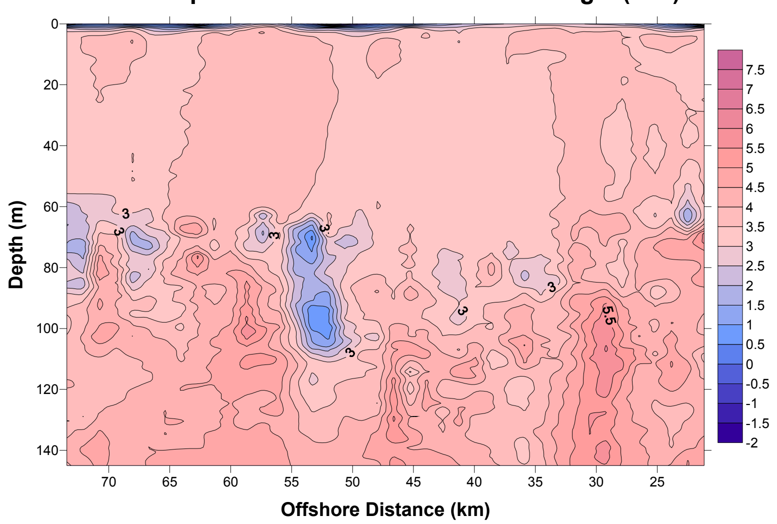
Sound Speed Plot for Triaxus Along Line 3 Leg 1 (m/s)



Sound Speed Plot for XBT Drops Along Line 3 Leg 1 (m/s)

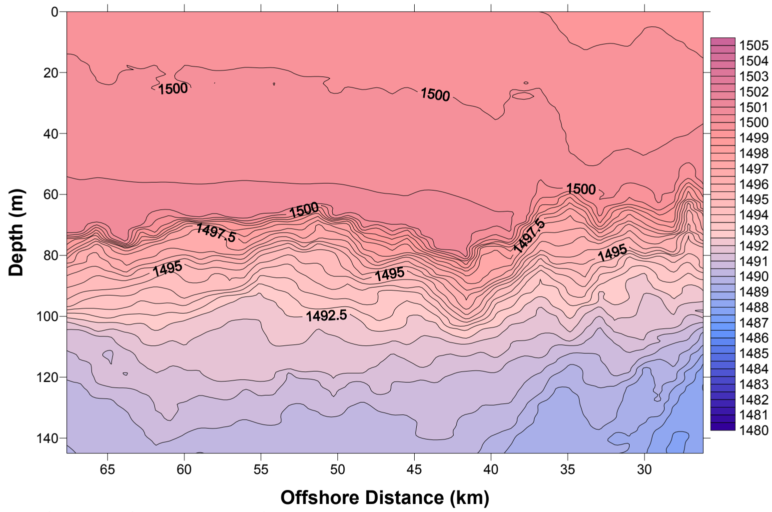


Sound Speed Difference Plot for Line 3 Leg 1 (m/s)

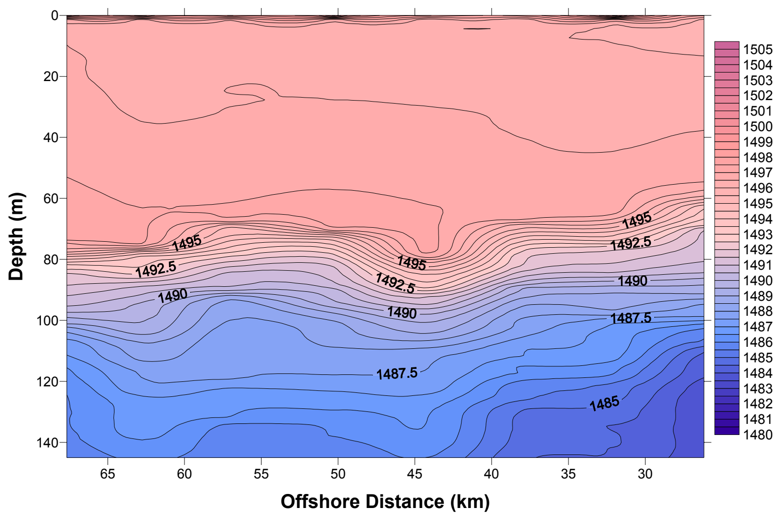


Appendix F

Sound Speed Plot for Triaxus Along Line 4b Leg 2 (m/s)



Sound Speed Plot for XBT Drops Along Line 4b Leg 2 (m/s)



Sound Speed Difference Plot for Line 4b Leg 2 (m/s)